12 Oct 1998
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PROPOSED NEW SECTION TO NSTM-582
SHIP OPERATOR MOORING GUIDELINES - PIERS AND WHARVES

1.0 Purpose. This section gives advice concerning ship operator inspection and mooring at piers and wharves from a facility perspective to help ensure safe mooring of surface ships.

2.0 Mooring Service Types. In order to provide safe mooring of ships, the types of mooring services shown in Table 2-1 are provided for ships.

Table 2-1. MOORING SERVICE TYPES

MOORING SERVICE TYPE	DESCRIPTION
TYPE I	This category covers moorings which are used for **up to one month** by a vessel that **will leave** prior to an approaching tropical hurricane, typhoon or flood. Moorings include ammunition facilities, fueling facilities, deperming facilities, and ports of call. Use of these moorings is normally selected concomitant with forecasted weather.
TYPE II	This category covers moorings which are used for **one month or more** by a vessel that **will leave** prior to an approaching tropical hurricane, typhoon or flood. Moorings include general purpose berthing facilities.
TYPE III	This category covers moorings which are used for **up to two years** by a vessel that **will not leave** prior to an approaching tropical hurricane or typhoon. Moorings include fitting-out, repair, drydocking, and overhaul berthing facilities. Ships experience this service approximately every five years. Facilities providing this service are nearly always occupied.
TYPE IV	This category covers moorings which are used for **two years or more** by a vessel that **will not leave** in case of a hurricane, typhoon or flood. Moorings include inactive, drydock, ship museum and training berthing facilities.

In these four types of mooring service, the facility is designed to keep the ship safely moored for the conditions at that site with very low risk of failure. For example, in Type II mooring service, the mooring should be able to resist either winds with a 50-year return interval or 75 mph (which ever is smaller). Table 2-2 summarizes the design criteria.

Table 2-2. SUMMARY OF FACILITY DESIGN CRITERIA FOR MOORING SERVICE TYPES

MOORING SERVICE TYPE	WIND	CURRENT	WATER LEVEL	WAVES
TYPE I	R=25 yr (min.) =75 mph (max.)	max. current	mean lower low to mean higher high	P=1 or R=1 yr

TYPE II	R=50 yr (min.) =75 mph (max.)	P=0.02 R=50 yr	extreme lower low to mean higher high	P=1 or R=1 yr
TYPE III	R=50 yr	P=0.02 or R=50 yr	extreme lower low to mean higher high	P=0.02 or R=50 yr
TYPE IV	R=100 yr	P=0.01 or R=100 yr	extreme water levels	P=0.01 or R= 100 yr

3.0 Mooring Facilities. The typical pier or wharf includes several key elements for ship mooring, including mooring fittings and fenders. Figure 3.1 shows a typical berth. In some cases camels are provided. All of these items must be in good condition and properly used to help ensure safe mooring.

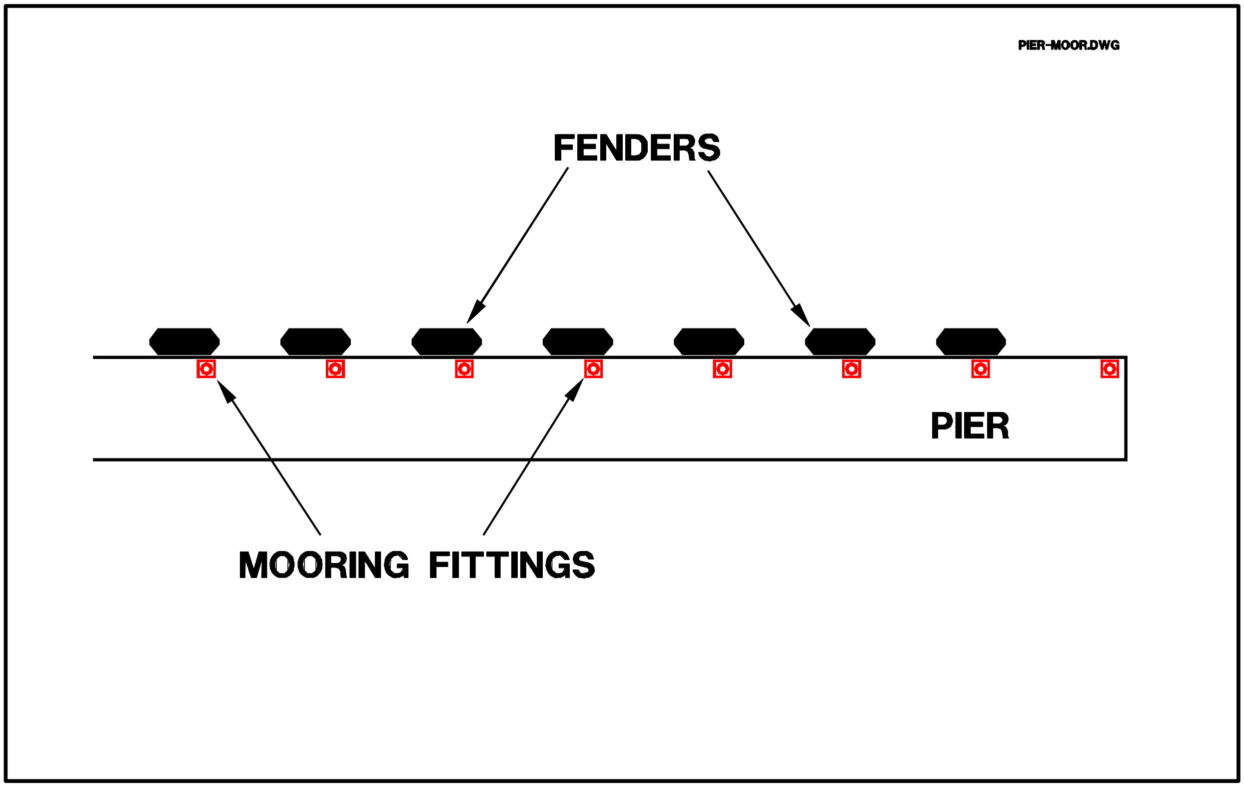


Figure 3.1 TYPICAL BERTH

3.1 Mooring Fittings. Mooring line fittings provided on piers and wharves are cast metal structures bolted into the concrete or wood structure. The strength of the bolts is usually the factor controlling the strength of the fitting. Mooring fittings on piers or wharves are designed with a higher factor of safety than mooring lines to help ensure that the fitting will hold with ships' mooring lines. Common mooring fittings are shown in Figure 3.2.

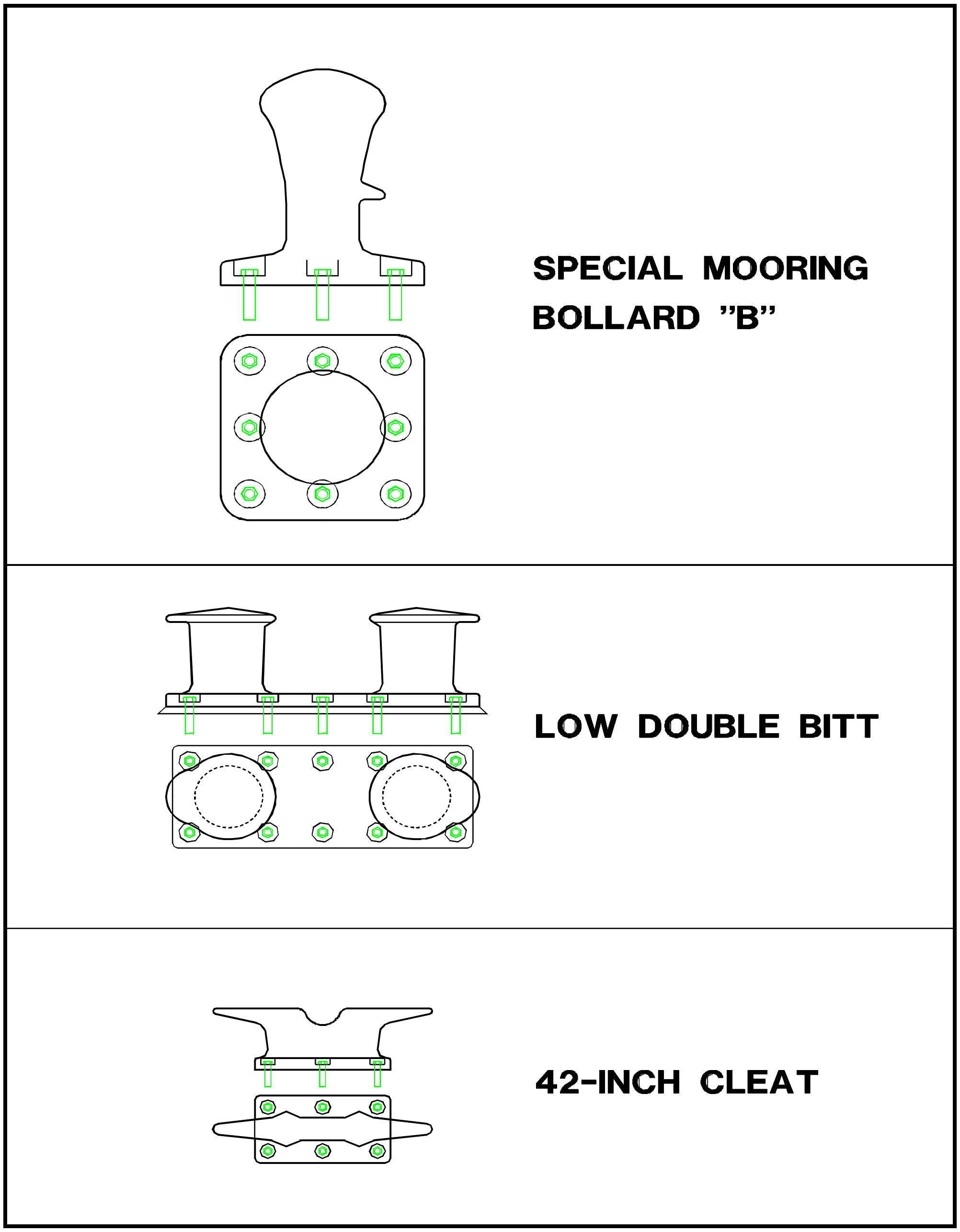


Figure 3.2 TYPICAL PIER/WHARF MOORING FITTINGS

3.1.1 Bollards. Bollards are single unit vertical structures for securing mooring lines. The upper sketch in Figure 3-2 illustrates a typical bollard. There are three standard bollard sizes that are used on U.S. Navy piers, as summarized in Table 3-1. The overall dimensions and number/size of the bolts can be used to identify the standard fittings. Bollards can be used with spring and breasting lines. Bollards are usually sized to accommodate multiple parts of line.

Table 3-1. COMMONLY USED U.S. NAVY SHORE BOLLARDS

DESCRIPTION	SIZE	BOLTS	WORKING CAPACITY (kips)
SPECIAL MOORING BOLLARD “A”	Height=48 in. Base 48x48 in.	12 x 1-in. dia.	Horz. = 660 @45 deg = 430 Nom. = 450
SPECIAL MOORING BOLLARD “B”	Height=44.5 in. Base 39x39 in.	8 x 2.25-in. dia.	Horz. = 270 @45 deg = 216 Nom. = 200
LARGE BOLLARD WITH HORN	Height=44.5 Base 39x39 in.	4 x 1.75-in. dia.	Horz. = 104 @45 deg = 66 Nom. = 70

* Additional information concerning the sizes and working capacities of pier and wharf mooring fittings is found in MIL-HKBK-1026/4 and MIL-HDBK-1025

3.1.2 Bits. Double bitts (Figure 3-2 center sketch) are commonly used on U.S. Navy piers and wharves. These shore-based bitts are similar to double bitts used on U.S. Navy ships, except that they are bolted down. Table 3-2 lists characteristics of the two standard size of bitts. Bitts are identified by their dimensions and number/size of bolts. Bitts are used to secure spring and breasting lines. Bitts are usually sized to accommodate multiple parts of line.

Table 3-2. COMMONLY USED U.S. NAVY SHORE BITTS

DESCRIPTION	SIZE	BOLTS	WORKING CAPACITY (kips)
LARGE DOUBLE BITT WITH LIP	Height=26 in. Base 73.5x28 in.	10 x 1.75-in. dia.	Nom. = 75*
LOW DOUBLE BITT WITH LIP	Height=18 in. Base 57.5x21.5 in.	10 x 1.625-in. dia.	Nom. = 60*

*working capacity per barrel; after NAVFAC Draw. No. 1404464
Additional information concerning the sizes and working capacities of pier and wharf mooring fittings is found in MIL-HKBK-1026/4 and MIL-HDBK-1025

3.1.3 Cleats. Cleats (Figure 3-2 lower sketch) are low capacity fittings. They are designed for small craft moorings and to assist ships getting into moorings. Due to their low capacity, cleats are primarily used for single parts of spring line. In most cases they should not be used for breasting lines, which should be run to bollards or double bitts.

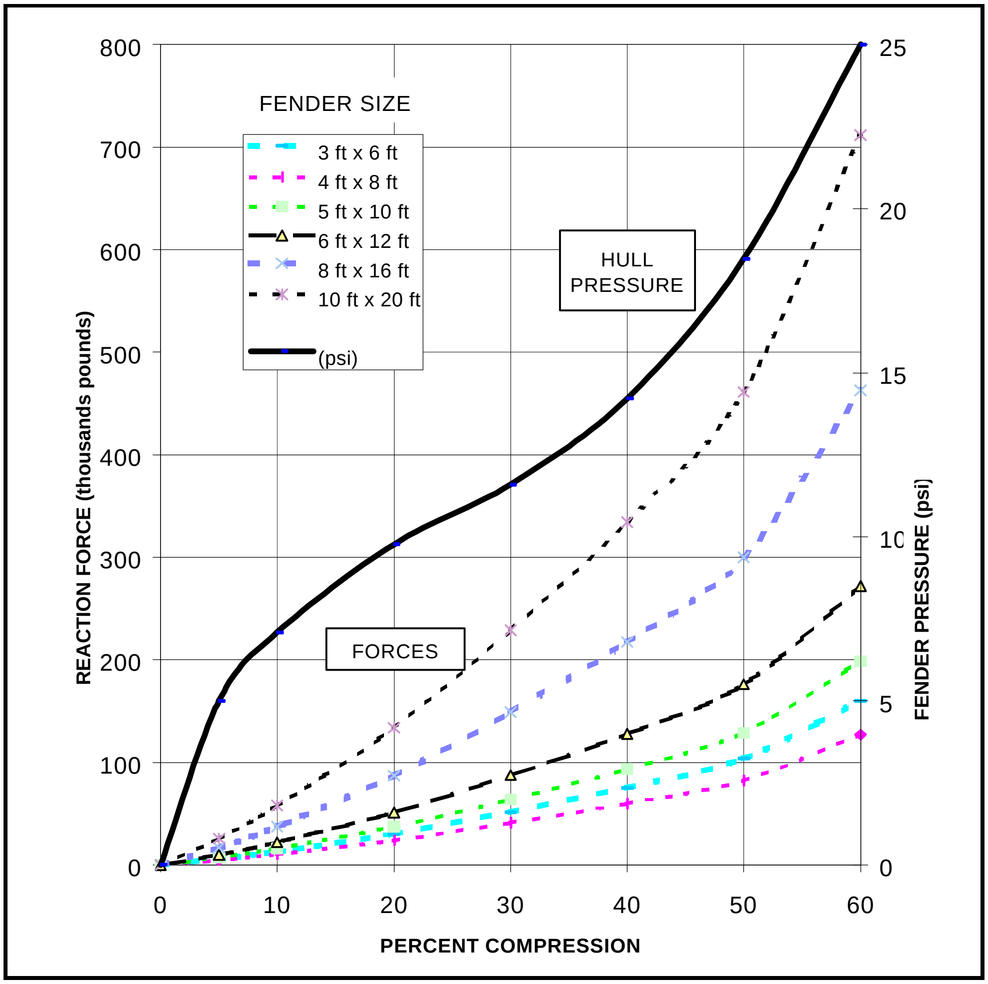
Table 3-3. COMMONLY USED U.S. NAVY SHORE CLEATS

DESCRIPTION	SIZE	BOLTS	WORKING CAPACITY (kips)
42-INCH CLEAT	Height=13 in. Base 26x14.25 in.	6 x 1.125-in. dia.	Nom. = 40
30-INCH CLEAT	Height=13 in. Base 16x16 in.	4 x 1.125-in. dia.	Nom. = 20

*Additional information concerning the sizes and working capacities of pier and wharf mooring fittings is found in MIL-HKBK-1026/4 and MIL-HDBK-1025

3.1.4 Other Fittings. Other mooring fittings that may be provided as some facilities include mooring dolphins or auxiliary mooring buoys. More information on these structures can be found in MIL-HDBK-1025 and MIL-HDBK-1026/4.

3.2 Fenders. Fenders are ‘cushioning’ devises for protecting a ship’s hull and the adjacent structure as the ship berths and during ship mooring. Fenders usually are made of artifical rubber or have rubber facing. Wood piles are also used as fenders. Figures 3-3 and 3-4 show characteristics of some commonly used foam-filled urethane coated fenders, which are referred to by diameter, length and type.



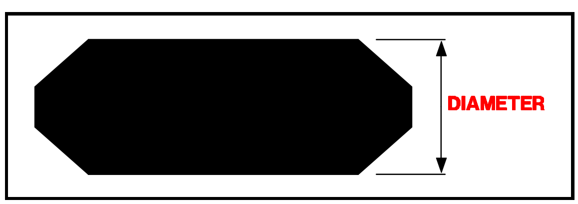


Figure 3-3. SEA-GUARD FENDER INFORMATION

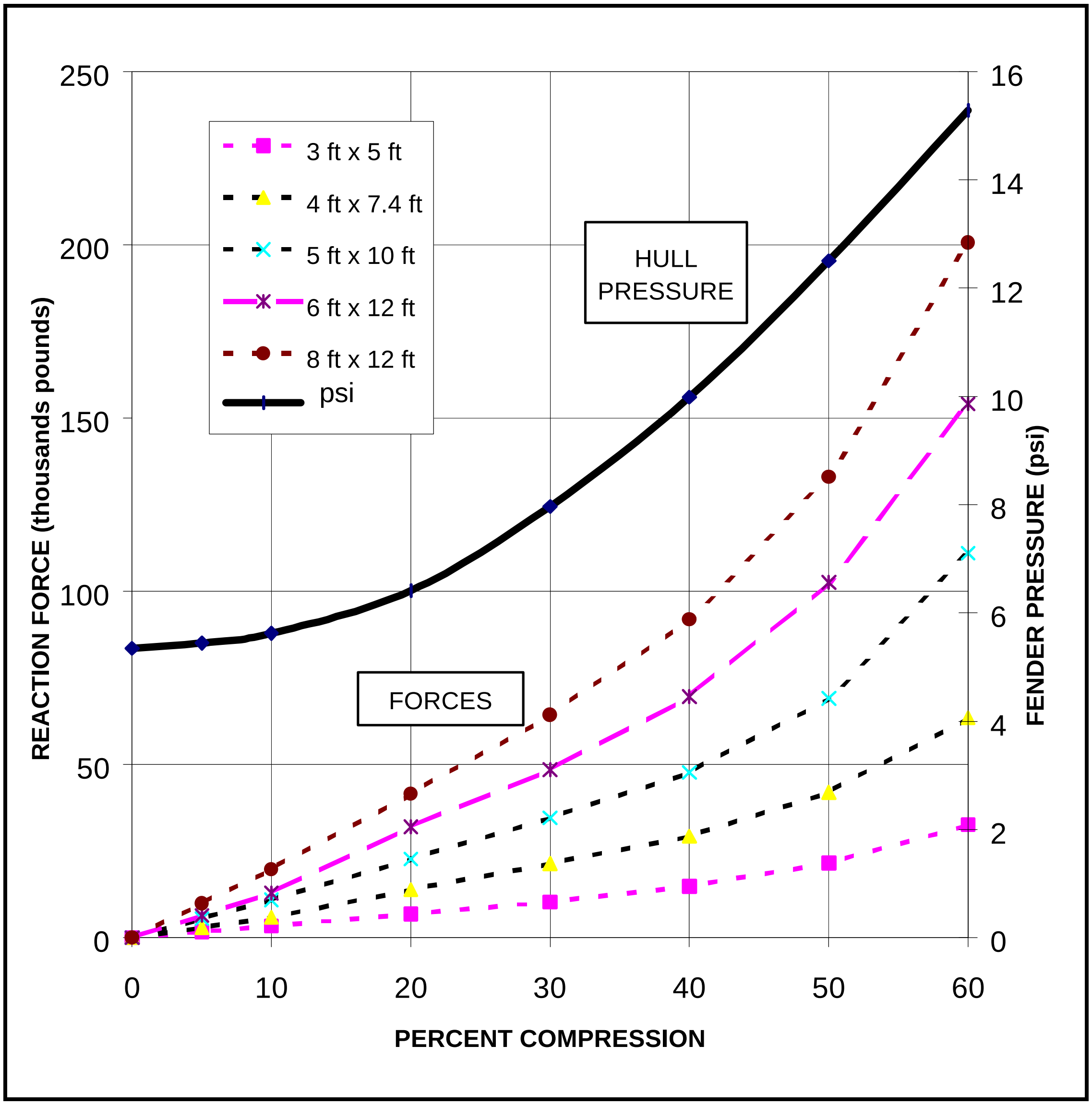


Figure 3-4. SEA-CUSHON FENDER PERFORMANCE

3.3 Camels. Camels are floating structures used to offshore ships from a pier or wharf. Camels are used to reduce interference between a ship and a structure and to improve mooring efficiency.

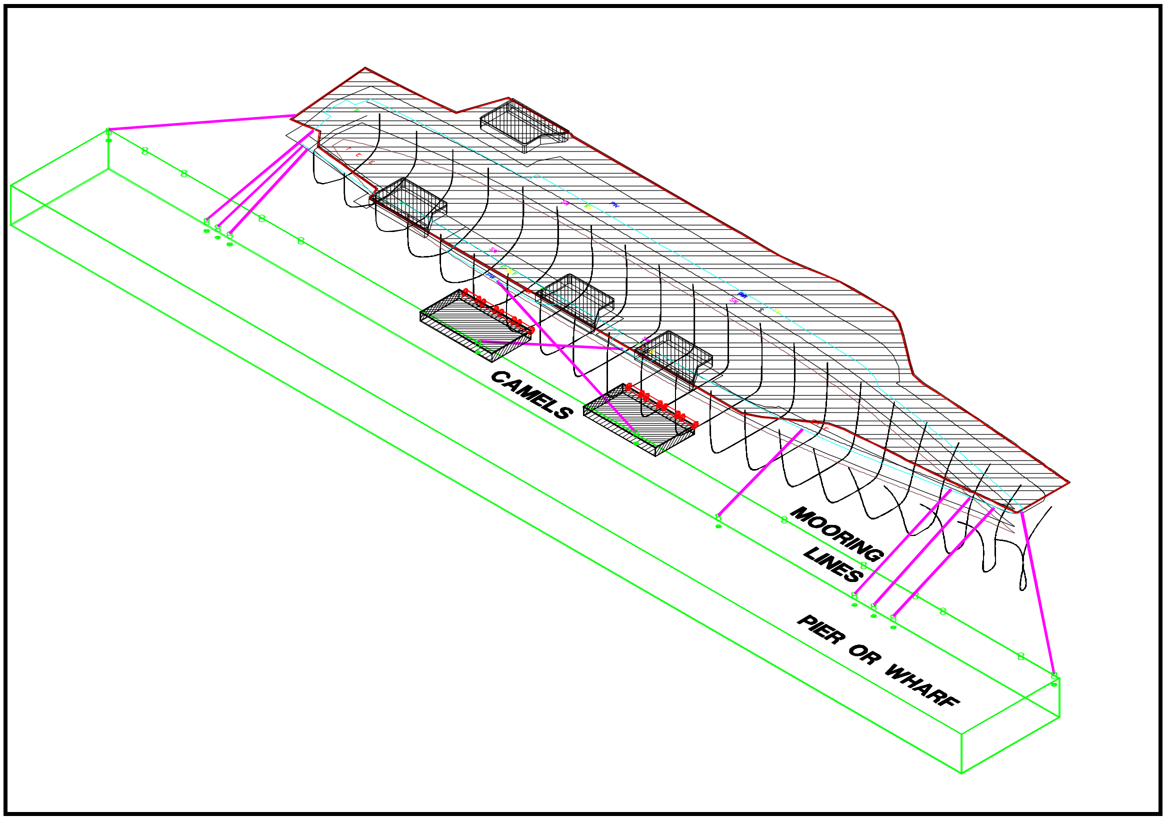


Figure 3-5. SAMPLE USE OF CAMELS FOR AN AIRCRAFT CARRIER

4.0 Recommended Actions/Ship Berth Inspections. Prior to fully mooring, there are several recommended actions that the ship should take, as summarized in Table 4.1.

Table 4.1 RECOMMENDED ACTIONS/INSPECTIONS PRIOR TO FULLY MOORING A SURFACE SHIP

ACTION	*DISCUSSION*
Check channel/tides/ currents/weather/traffic	Check with Port Ops and the Harbor Pilot the to ensure access to the port (channel depth, channel width, clearance under bridges) is adequate; determine tide levels and currents; coordinate with harbor traffic and other ship mooring; and determine the weather to ensure it is safe to enter the port. Ensure adequate tug, utilities and shore support are available.
Check berth	Check with Port Ops, the Harbor Pilot and Public Works that the water depth at the berth, length of the berth, strength of the pier and condition of the berth are adequate and suitable for the given class of ship.
Check fenders and camels	Check with Port Ops and the Harbor Pilot to be sure the fenders and camels on the pier/wharf are in good condition and suitable.
Keep berthing velocity low	The kinetic energy of the ship goes up dramatically as the ship speed increases. Therefore, it is recommended that the ship velocity be kept to 1.5 foot per second (0.9 knot).
Inspect mooring fittings	Make a visual check of all mooring fittings to determine what capacity they are, where they are located and make sure they are in good working order. Mooring fittings should not be used if they are cracked, bolts are missing or if the pier/wharf is cracked/damaged in the area of the fitting. In general bollards and bitts should be used for mooring; cleats should not be used unless absolutely necessary.

4.1 Suitability of Mooring Fittings. When a ship moors at a pier or wharf, there are usually a number of mooring fittings that can be used. The approach taken for U.S. Navy ship moorings is to develop the 'best' mooring using existing fittings and at the same time not overload the mooring fittings. Therefore, the number, size and parts of lines run to a single fitting need to be specified so that the fitting is not overloaded.

Mooring fittings come in different sizes and strengths. Bollards and bitts are designed for mooring. Cleats have low strength and are usually designed only for small craft or to assist in mooring. Cleats should not be used for mooring unless absolutely necessary.

Table 4.2 shows standard size mooring fittings and shows the maximum line sizes that can be used if three parts of line are secured to a fitting. Table 4.3 shows the maximum line size that can be used if only one part of line is used on a fitting.

Table 4.2 MOORING FITTING USE FOR THREE PARTS OF LINES (I.E. 'DOUBLED UP' LINES)

DESCRIPTION	WORKING CAPACITY (kips)	MAX. CIR. DOUBLE BRAIDED POLYESTER	MAX. CIR. DOUBLE BRAIDED NYLON	MAX. CIR. ARAMID LINE (KEVLAR, SPECTRA, ETC.)
SPECIAL MOORING BOLLARD "A"	Horz. = 660 @45 deg = 430 Nom. = 450	12 inch	12 inch	7.5 inch
SPECIAL MOORING BOLLARD "B"	Horz. = 270 @45 deg = 216 Nom. = 200	8 inch	7.5 inch	5.5 inch
LARGE BOLLARD WITH HORN	Horz. = 104 @45 deg = 66 Nom. = 70	4.5 inch	4.5 inch	3 inch
LARGE DOUBLE BITT WITH LIP	Nom. = 75*	6 inch**	5.5 inch**	4 inch**
LOW DOUBLE BITT WITH LIP	Nom. = 60*	5 inch**	5 inch**	3.5 inch**
42-INCH CLEAT	Nom. = 40	3 inch	3 inch	-
30-INCH CLEAT	Nom. = 20	-	-	-

*working capacity per barrel
** use both bitts

Table 4.3 MOORING FITTING USE FOR A SINGLE PART OF LINE

DESCRIPTION	WORKING CAPACITY (kips)	MAX. CIR. DOUBLE BRAIDED POLYESTER	MAX. CIR. DOUBLE BRAIDED NYLON	MAX. CIR. ARAMID LINE (KEVLAR, SPECTRA, ETC.)
SPECIAL MOORING BOLLARD “A”	Horz. = 660 @45 deg = 430 Nom. = 450	-	-	-
SPECIAL MOORING BOLLARD “B”	Horz. = 270 @45 deg = 216 Nom. = 200	14 inch	14 inch	-
LARGE BOLLARD WITH HORN	Horz. = 104 @45 deg = 66 Nom. = 70	8 inch	8 inch	6 inch
LARGE DOUBLE BITT WITH LIP	Nom. = 75*	8.5 inch	8.5 inch	6 inch
LOW DOUBLE BITT WITH LIP	Nom. = 60*	7.5 inch	7 inch	5 inch
42-INCH CLEAT	Nom. = 40	6 inch	6 inch	4 inch
30-INCH CLEAT	Nom. = 20	4 inch	4 inch	2.75 inch

*working capacity per barrel
** use both bitts

5.0 <u>Guidelines for Mooring</u>.

5.1 Mooring. The purpose of mooring is to keep the ship safely secured at the berth and to prevent excessive ship motions. Successful mooring requires that an adequate number of mooring lines be deployed, that they be put in the correct arrangement and that they are properly deployed.

The approach taken in modern mooring is that a number of lines be deployed, often with one, two or three parts of line extending from each pier fitting to each ship fitting. Lines must be arranged so that none of the mooring fittings are overloaded. Note that when three parts of line are deployed this is called ‘doubling up’.

The way a mooring works is that a number of lines help share the potentially large loads that can occur on a ship. These lines must resist forces and motions for the ship in the surge, sway and yaw directions of motion. The ship buoyancy supports the ship in the heave, roll and pitch directions.

5.2 Mooring Lines. The ship is responsible for providing mooring lines at most facilities. The only exception is that a contractor is required to provide suitable mooring lines when a ship is in availability under repair at a contractor’s facility. Some of the more common lines are discussed below.

5.2.1 Polyester lines. These have some ability to stretch to aid in load sharing and provide for water level changes.

5.2.2 Nylon lines. Can stretch a great deal, which is ideal for load sharing and provide for water level changes. However, when a nylon line stretches it builds up a tremendous amount of energy, so if a line breaks the ends can kill in ‘snap back’. Therefore, nylon lines must be used very carefully.

5.2.3 Aramid lines. Kevlar, spectra and some of the other new lines have some good features: (1) they are small, light and easy to handle for a given strength, and (2) if a line breaks it does not snap back. However, these lines are extremely stiff, meaning that they do not stretch very much, even under high loads. Aramid lines therefore are difficult to get load sharing between the different mooring lines. These lines also have to be tended as water levels change. The typical surface ship may have millions of pounds of buoyancy force as the tide rises. If the aramid lines are not tended, then the lines can be overloaded as the tide rises, because the lines are very stiff and stretch little as the tide rises.

5.3 General Mooring Arrangement. A general mooring arrangement for surface ship mooring consists of spring and breasting lines, as shown in Figure 5-1.

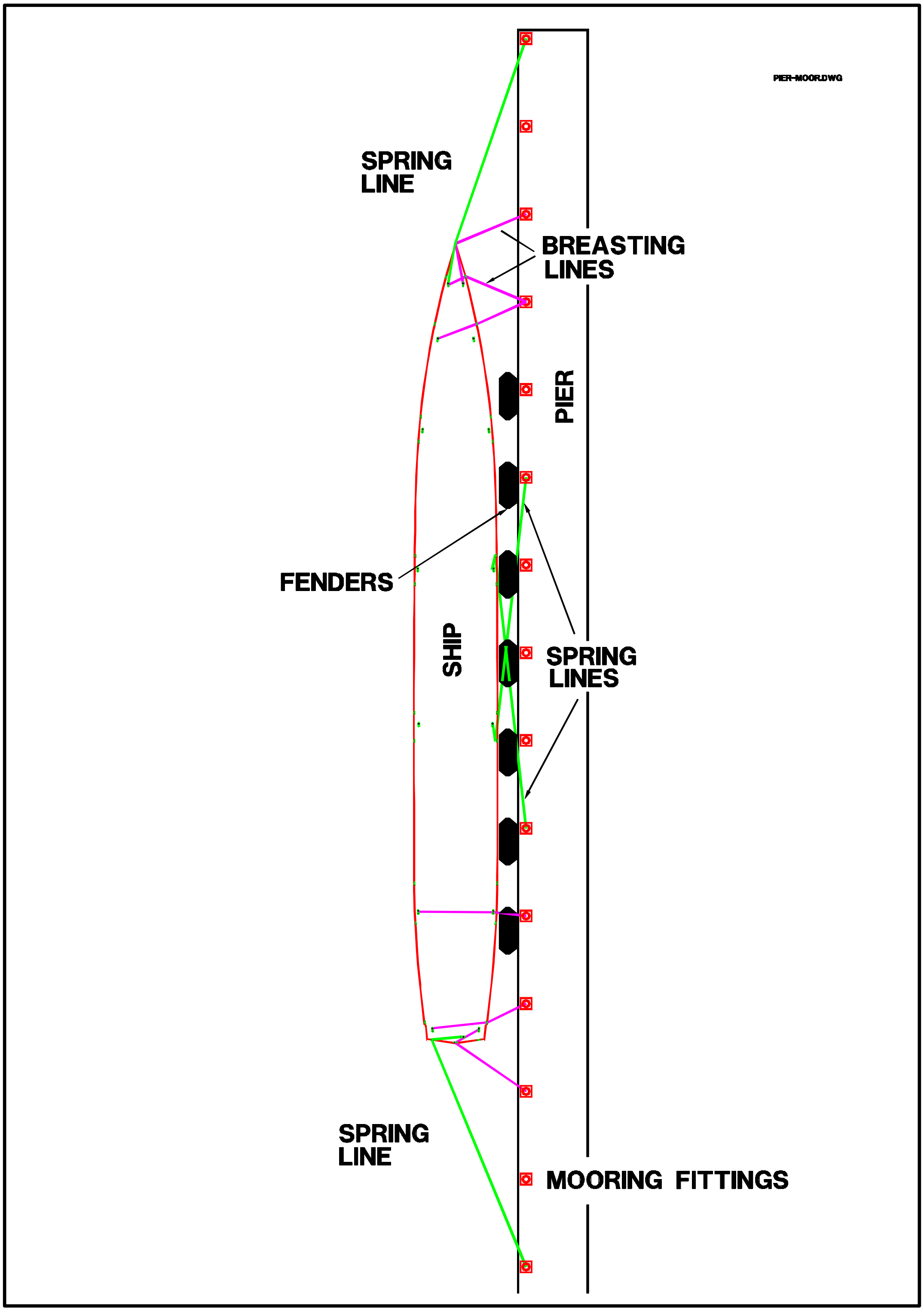


Figure 5-1. TYPICAL MOORING ARRANGEMENT

5.3.1 Spring lines. A spring line is defined as a line with an angle less than 45 degrees to the berth, as shown in Figure 5-1. Modern ships are streamlined in the longitudinal direction. This means that the wind and current forces in the longitudinal direction on a ship are relatively low. Therefore, the number of spring lines required is modest. In most cases two or four spring lines can safely moor a ship. Key features of spring lines are that they should be: (1) kept at a small angle to the pier face to resist longitudinal wind and current forces, (2) kept long for good load sharing, and (3) kept at small vertical angles, so tidal effects are small.

5.3.2 Breasting lines. A breasting line is defined as a line with an angle greater than 45 degrees to the berth, as shown in Figure 5-1. Most ships have relatively large broadside wind and submerged areas. Also, many ships use berths with relatively small underkeel clearance. This combination of conditions means that high forces and moments can occur on a ship in the sway and yaw directions. Therefore, a relatively large number of breasting lines may be required to safely moor a ship.

5.4 Advice and Rules-of-Thumb for mooring line arrangement.

Any mooring member is only as strong as the weakest link. Therefore, the line working strength times the number of mooring line put on a ship mooring fitting and pier mooring fitting should not exceed the working strength of the fittings.

5.4.1 Number of mooring lines.

The number of mooring lines put out should meet Mooring Service Type criteria consistent with facility use (see Table 2-1). These criteria are recommended, because some storms (thunderstorms, etc.) can come up quickly and it takes time to get extra parts of line out. It is important to remember that forces and moments on a ship increase as the square of the wind speed. This means that only modest increases in the wind speed can result in large increases in mooring line tension.

Forces and moments on most ships are such that mooring lines should be arranged in pairs, when possible. Equal numbers of breasting lines should be placed near the bow and stern. Also, equal numbers of spring lines should be towards the bow and towards the stern.

5.4.2 Line angles. It is best to arrange lines as follows:

Breasting lines - Approximately perpendicular to the ship centerline with small up angles

Spring lines - At small angles to the ship centerline with small up angles

5.4.3 Line lengths.

Breasting lines should all have similar lengths, if possible, to aid in load sharing. Both breasting and spring lines should be kept long, if possible, to reduce the effects of water level changes.

5.4.4 Load Sharing.

Breasting lines should all have approximately the same stiffness, when ever possible. One way to achieve this for the case of all lines of the same materials and size is to keep the breasting line lengths apprxomately the same. This aids in load sharing. If the pier fittings are such that the lines cannot be made to be of similar length, then lines should be run across the deck and secured to ship's bitts across the deck, as illustrated in Figure 5-2.

Figure 5-2. SAMPLE OF RUNNING LINES ACROSS THE DECK

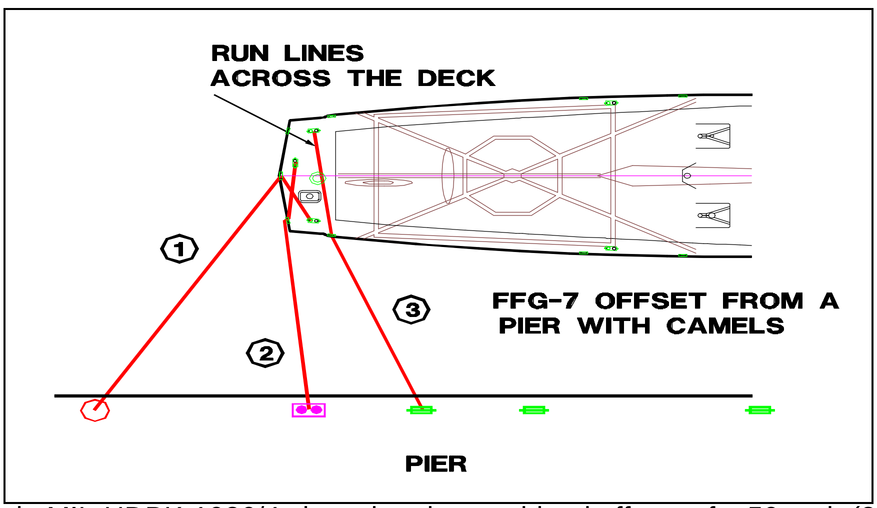
5.4.5 Pretension in lines. In most cases lines should have a small amount of pretension applied at approximately the mean tide condition.

5.5.6 Tending lines. In cases where very stiff lines are used (such as Kevlar or Spectra), then lines need to be tended to prevent over loading of lines. This is especially critical where the tidal range is large. Keeping the vertical angle of lines low can minimize tidal effects.

5.5.7 Use of camels. Camels should be placed as far as possible for and aft of the ship's mid-point. Camels should be placed where the hull is approximately straight and in a way to avoid interferences.

5.5 Example - Mooring USS TARAWA (LHA 1)

Mooring USS TARAWA LHA-1, an amphibious ship with large broadside area and ship mooring fittings high off the water, is used as an example. The ship is illustrated in Figure 5-3. In this case the ship is moored alongside a pier. The pier elevation is 10 feet (3.3 m) and has bollards with 200 000 pounds (0.89 MN) of working holding capacity placed every 60 feet (18 m). The ship draft is taken as 26 feet (7.9 m). The current speed is 1 knot (0.5 m/s) in the broadside direction pushing the ship off the pier. It is not known which direction the wind may blow in a given storm, so the ship must be safely moored to resist wind from any direction.



Methods in MIL-HDBK-1026/4 show that the combined effects of a 50 mph (22.4 m/s) wind and 1 knot (0.5 m/s) current broadside pushing the LHA 1 off the pier produces a force of 563 000 pounds (2.5MN). If, on the other hand, the wind blows bow-on to the ship, then the wind force is
27 400 pounds (0.12 MN). This example shows that the wind force on the ship in the sway direction can be on the order of 20 times larger than in the surge direction, as illustrated in Figure 5-4. Therefore, many more breasting lines are required than spring lines.

Here we take the approach that the ship needs to be moored as safely as possible. Therefore, as many lines as practical are run from ship's mooring fittings to pier fittings. In this case 14 lines is a practical number of mooring lines.

Three different configurations are considered, as shown in Figure 5-5:

PLAN A - Mooring the ship alongside the pier with marine fenders between ship and pier.

PLAN B - Using 32-foot wide YC barges and marine fenders as camels to offset the ship from the pier.

PLAN C - In an emergency camels could be used and the mooring lines run across the pier. This is ususally not done, because the lines partly block access to the pier.

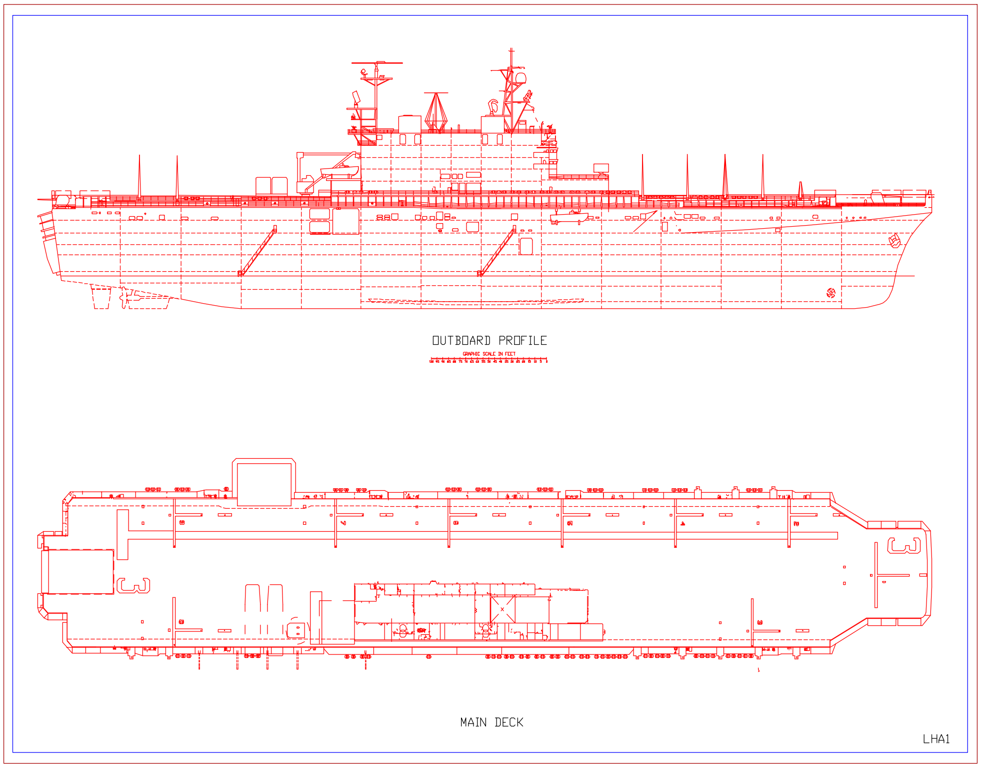


Figure 5-3. USS TARAWA (LHA 1)

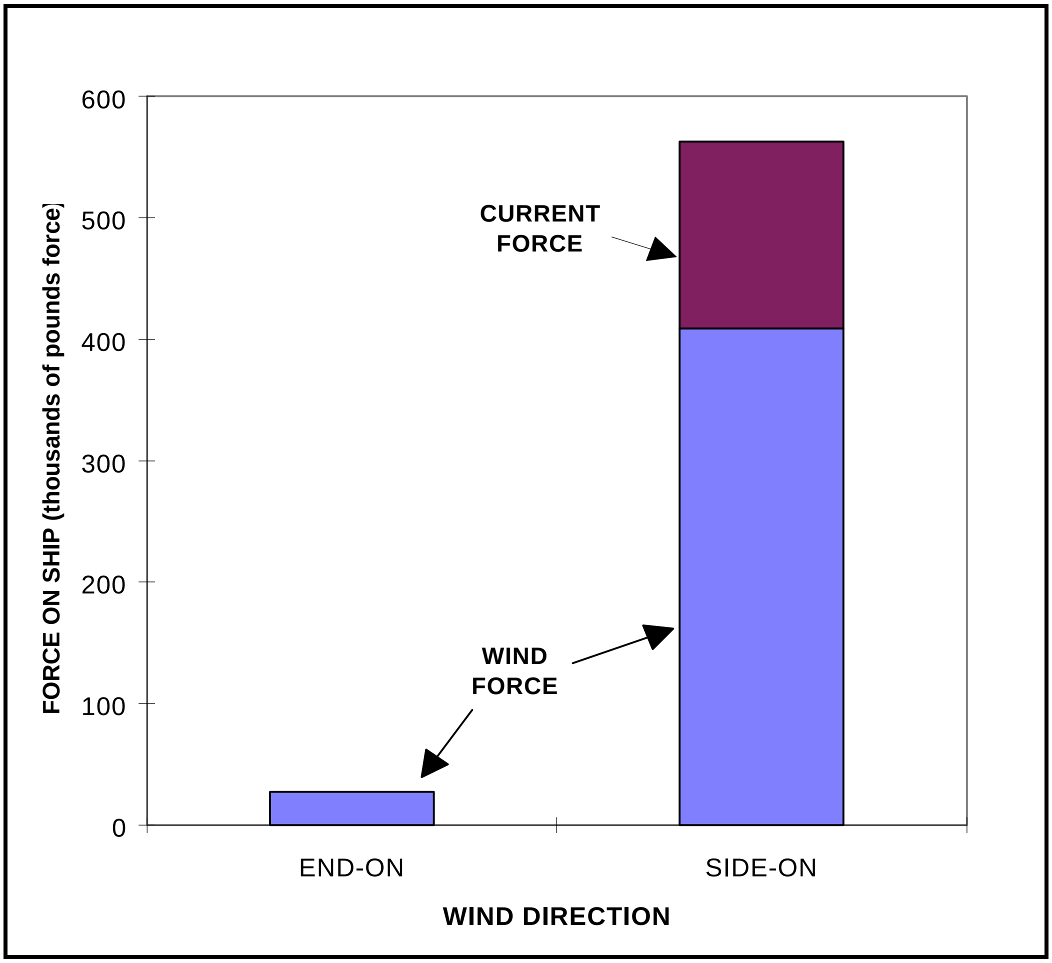


Figure 5-4. SAMPLE ENVIRONMENTAL FORCES ON LHA 1
(ship draft of 26 feet, broadside current speed
of 1 knot, wind speed of 50 mph)

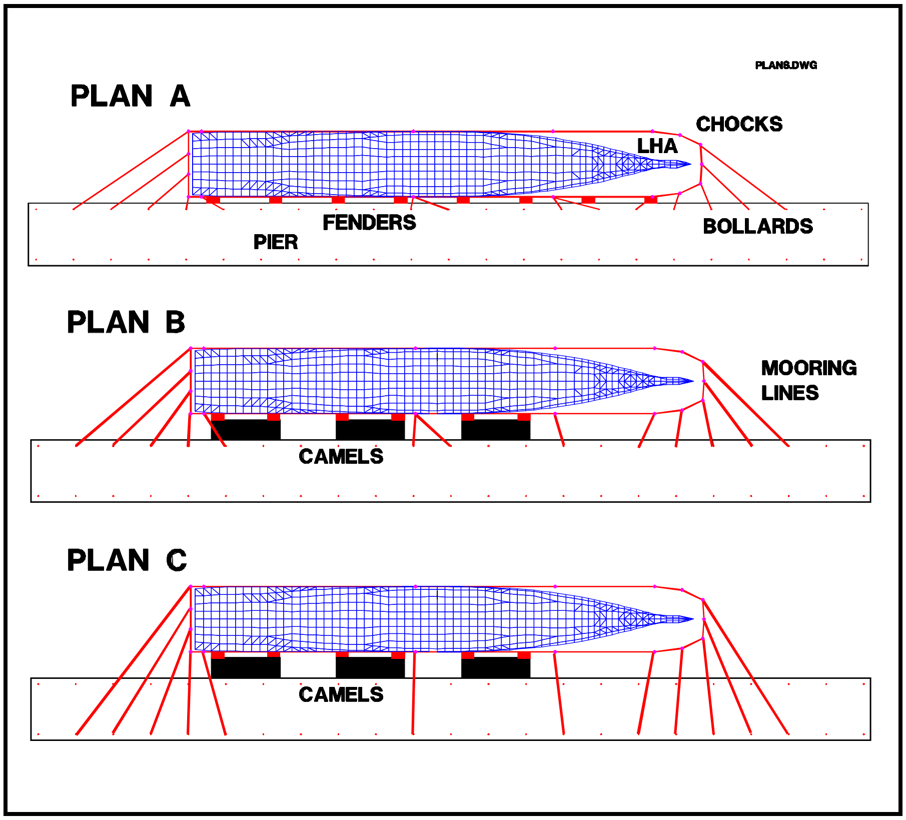


Figure 5-5. MOORING PLANS CONSIDERED IN THE LHA MOORING EXAMPLE

PLAN A is a ‘typical’ mooring configuration with mooring lines run from the ship to adjacent bollards on the pier, as shown in Figure 5-5. A key problem with this plan is that the mooring lines have large vertical angles, as shown in Figure 5-6, while the wind and current forcing is parallel to the water surface. This means that the vertical component of mooring line holding is providing no benefit in holding the ship at the pier.

Plans B and C put greater spacing between the ship and pier mooring fittings by adding camels and running the lines across the pier, as shown in Figure 5-5. This has three major benefits. First, the vertical line angle is decreased, so the lines are more effective at resisting wind and current forces, which are parallel to the water surface. Second, the mooring lines are longer and more equal in length and stiffness, so loading sharing between the mooring lines improves. Third, as the water level changes there is less effect, so the lines may not have to be tended.

In these example, 7.5-inch double braided polyester lines with a break strength of 180 000 pounds (0.8 MN) are assumed. Polyester is specified because it has good stretch-strain properties to aid in load sharing and because it has excellent fatigue resistance.

Detailed engineering analyses were performed on these mooring plans in accordance with MIL-HDBK-1026/4. Table 5-1 and Figure 5-7 show the maximum safe wind speed for the various plans. In this example, increasing the horizontal spacing between the ship and pier mooring fittings greatly increases the efficiency and safety of the mooring. Mooring efficiency, which is a measure of how effectively the mooring line strength is being mobilized to safely moor the ship, greatly increases as horizontal distance is added. This is mainly because the LHA mooring fittings are so high off of the water.

Adding parts of line also improves the mooring safety, because the overall strength of the mooring tension members increases.

Using PLAN A with 14 mooring lines of one part each is predicted to be safe in up to only 21 mph winds. In this case there may be a high degree of risk if a sudden storm comes up and the crew is unable to get more parts of mooring line deployed. Based on these results, 14 lines of 3 parts each are recommended for LHA mooring and camels should be seriously considered. In an emergency, lines should be run across the pier (PLAN C).

Table 5-1. MAXIMUM SAFE WIND SPEED FOR MOORING AN LHA-1 USING 14 SETS OF MOORING LINES

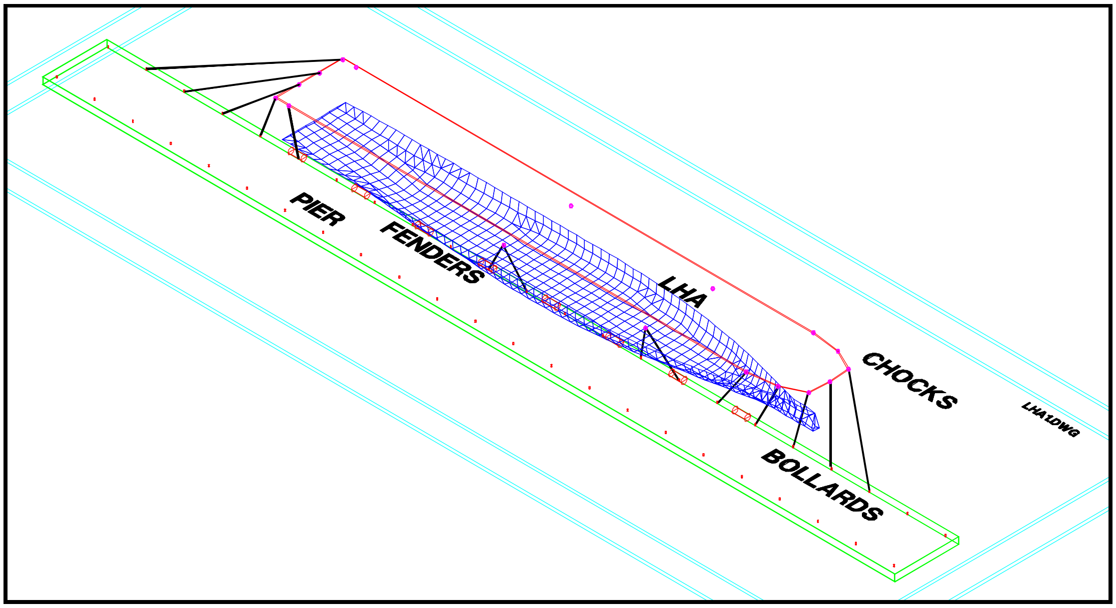
(a) Mooring Efficiency

	PLAN A	*PLAN B*	*PLAN C*
Efficiency	0.286	0.494	0.675

(b) Maximum Safe Wind Speed*

14 MOORING LINES	*PLAN A*	*PLAN B*	*PLAN C*
1 Part of Line	21 mph	36 mph	45 mph
2 Parts of Line	40 mph	58 mph	69 mph
3 Parts of Line	52 mph	73 mph	87 mph

* LHA-1 with draft of 26 feet, 1 knot current, 10-foot high pier with bollards of 200 000 pounds working capacity placed every 60 feet, 7.5 inch double braided polyester lines.



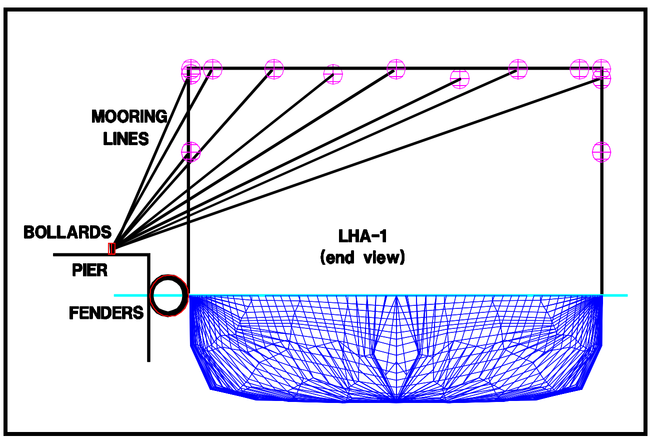


Figure 5-6. LHA-1 MOORING 'PLAN A' SHOWN IN PERSPECTIVE AND END VIEWS

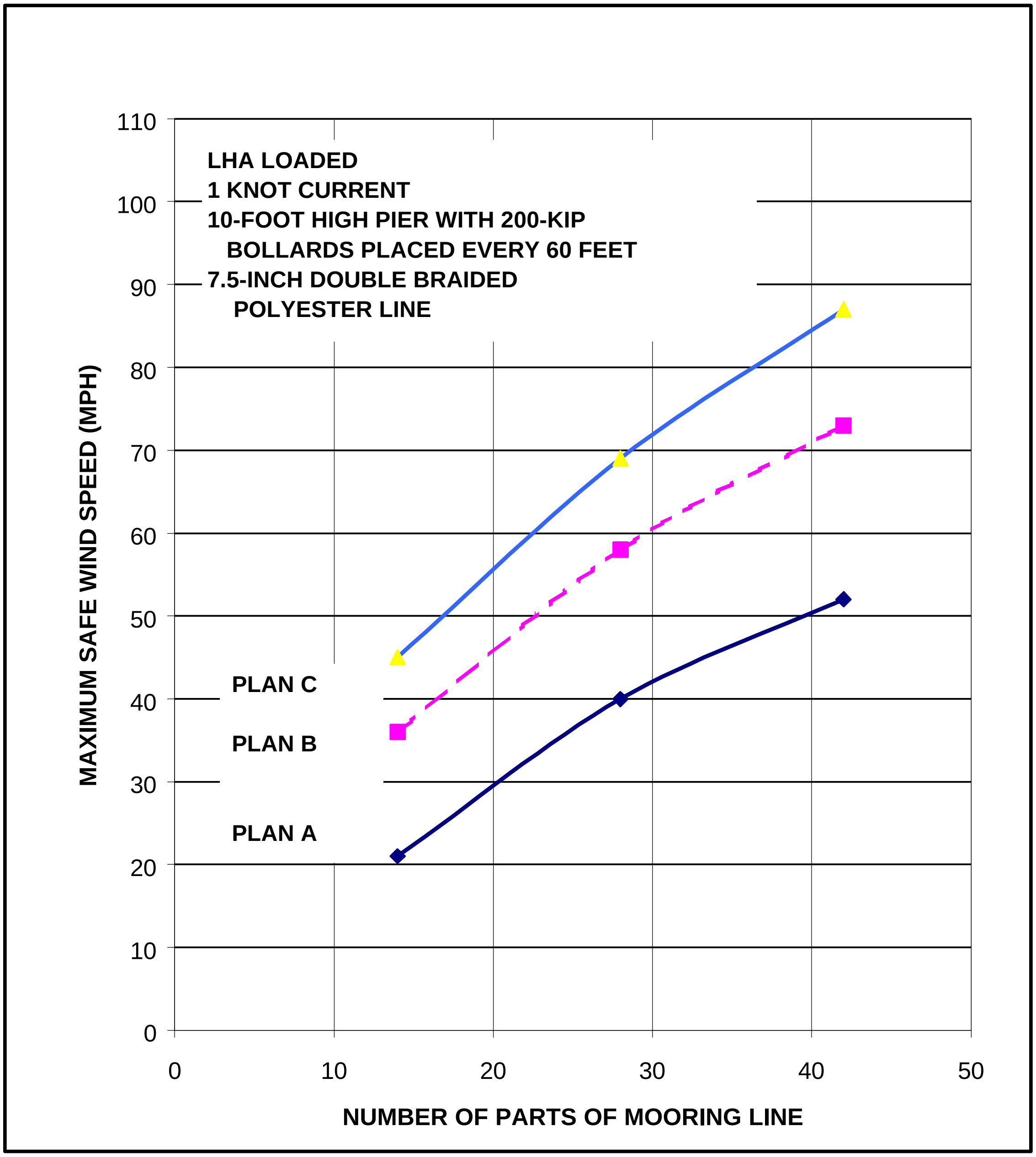


Figure 5-7. EXAMPLE - MAXIMUM SAFE WIND SPEEDS FOR VARIOUS LHA-1 MOORING PLANS